DESCRIPTION:

The model F3A-03HS02C-A02T2K5J is a high accuracy magnetic flux density-to-analogue-voltage transducer with a high-level and temperature compensated output signal for each of the three components (Bx, By, Bz) of the measured magnetic flux density within the measurement range ±2 T (±20 kG).

The temperature measurement feature allows user to take temperature readings while monitoring the magnetic field.

The Hall probe is connected with an electronic box (Module E in Fig. 2). The Module E provides biasing for the Hall probe and additional conditioning of the Hall probe output signals: amplification, linearization, cancelling offset, compensation of the temperature variations, and limitation of the frequency bandwidth.

The outputs of the transducer are available at the connector CoS of the Module E:

- three high-level differential voltages (Vx, Vy, Vz) proportional with each of the measured components (Bx, By, Bz, respectively) of a magnetic flux density, and
- a ground-referred voltage (Vpt) proportional with the actual local Hall sensor temperature.

TYPICAL APPLICATIONS:

- Characterization and quality control of permanent magnets
- Development of magnet systems
- Mapping magnetic field
- Quality control and monitoring of magnet systems (generators, motors, etc.)
- Application in laboratories and in production lines, etc.

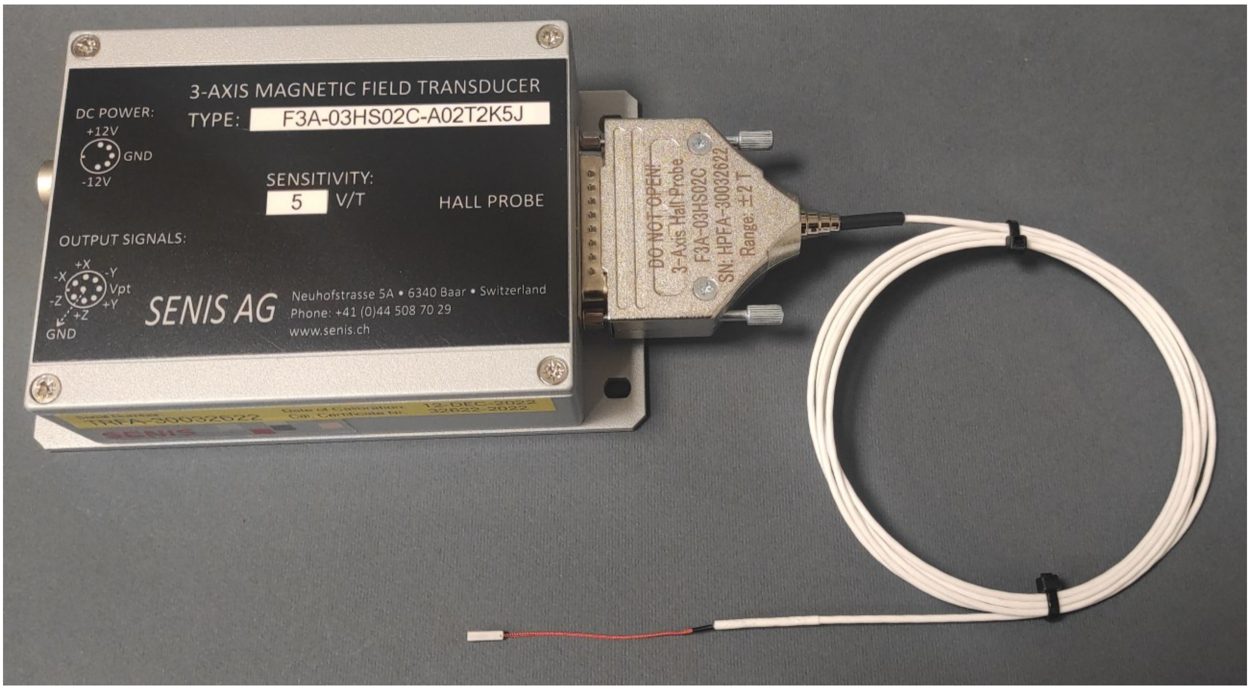


Figure 2. 3-axis magnetic field transducer type F3A-03HS02C-A02T2K5J

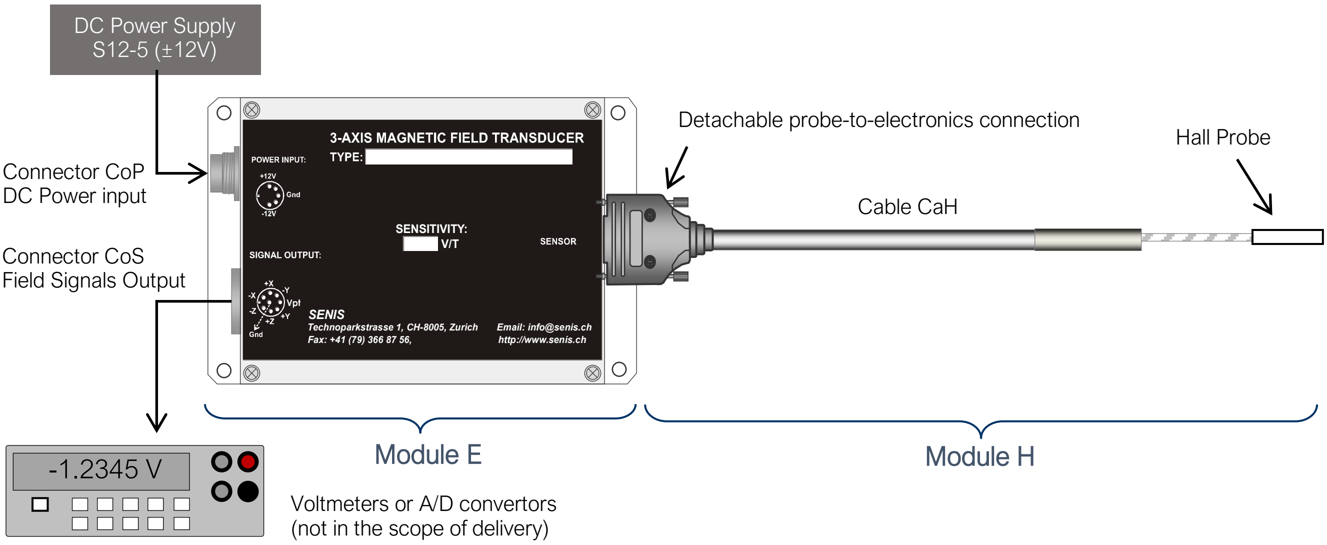


Figure 2. Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with fully integrated 3-axis Hall Probe (Module H) and Electronic (Module E)

SPECIFICATIONS (Module H):

The HS Hall probe for the SENIS F3A analog magnetic field transducers and 3MH3A digital teslameters is a thin (0.75 mm) and short (8 mm) single-chip fully integrated 3-axis Hall Probe.

The HS probe contains a CMOS integrated circuit, which incorporates three groups of mutually orthogonal Hall elements, biasing circuits, amplifiers, and a temperature sensor.

The integrated Hall elements occupy very small area (150 x 150 μm^2), which provides very high spatial resolution of the probe.

The CMOS IC technology enables very high precision in the fabrication of the vertical and horizontal Hall elements, which gives high angular accuracy of the three measurement axes of the probe (mutual orthogonality error is < 1°, determined with an accuracy of < 0.1°).

The on-chip application of the spinning-current technique in the biasing of the Hall elements suppresses the planar Hall-effect. The on-chip signal pre-processing enables a very high frequency bandwidth (DC - 25 kHz) of the probe, and on-chip signal amplification provides high output signals of the Hall probe.

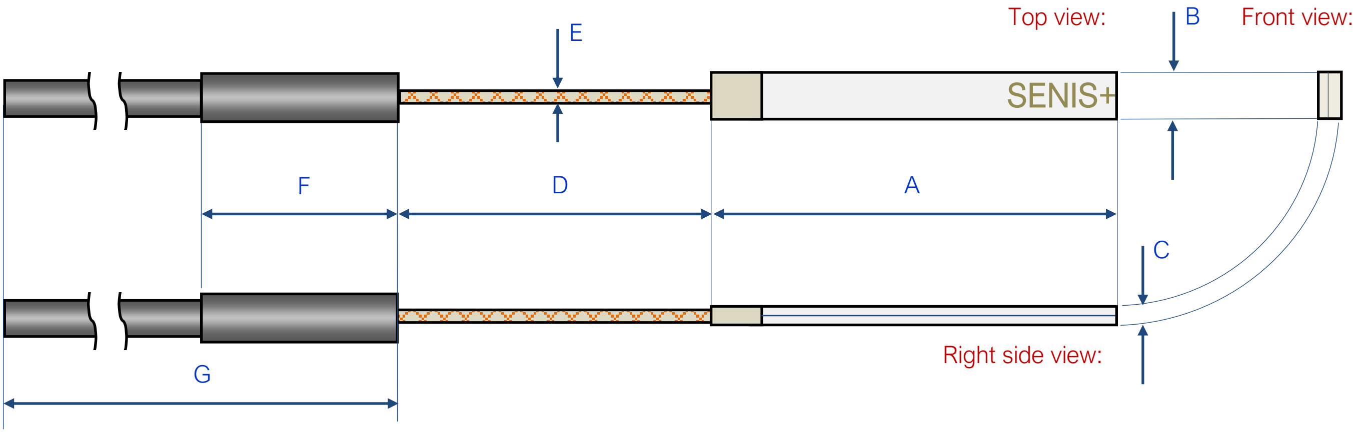
The sensor chip is embedded in the probe package and connected to the CaH cable.

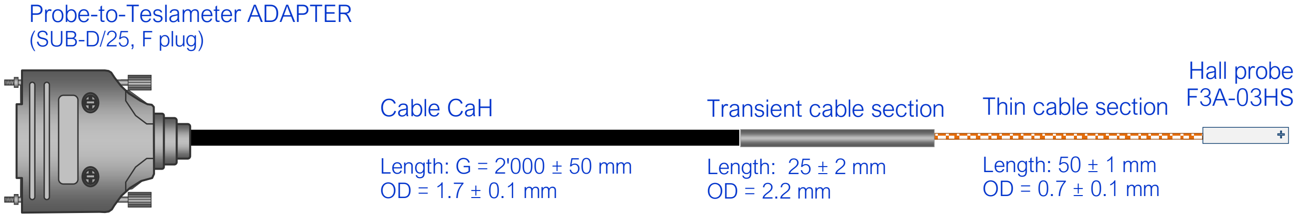
The outputs of the Hall Probe are high-level analog voltages proportional with each of the measured components of a magnetic flux density and a voltage proportional to the actual local temperature of the silicon Hall sensor.

Key features of the HS Hall probe

- HS is a thin (0.75 mm) and short (8 mm) 3-axis Hall probe type
- Probe package is fully made of Al_2O_3 ceramic, with the chip and cable connecting pads directly printed on the ceramic substrate
- Fully integrated CMOS 3-axis (Bx, By, Bz) Hall Probe, of which one, two, or three channels are used
- Very high spatial resolution: By: 0.03 x 0.005 x 0.03mm^3; Bx & Bz: 0.15 x 0.01 x 0.15 mm^3
- High angular accuracy (mutual orthogonality error is < 1°, determined with an accuracy of better than 0.1°)
- High frequency bandwidth:
  - standard: DC to 2.5 kHz (-3 dB point of sensitivity attenuation)
  - maximum: DC to 25 kHz (-3 dB point of sensitivity attenuation)
- Virtually no planar Hall effect
- Negligible inductive loops on the Probe
- Integrated temperature sensor on the probe for temperature compensation

Hall Probe and Cable: Mechanical Specifications





Dimension	Measure (mm)
A	8.0 ± 0.2
B	2.00 ± 0.05
C	0.75 +0.05/-0.00
D	50 ± 1
E	Ø 0.7 ± 0.1
F	25 ± 2
G*	2'000 ± 50

* NOTE: Different cable lengths (specification G) are available on a demand.

Figure 3. Dimensions and tolerances of the H-module (Hall probe and Cable) F3A-03HS02C

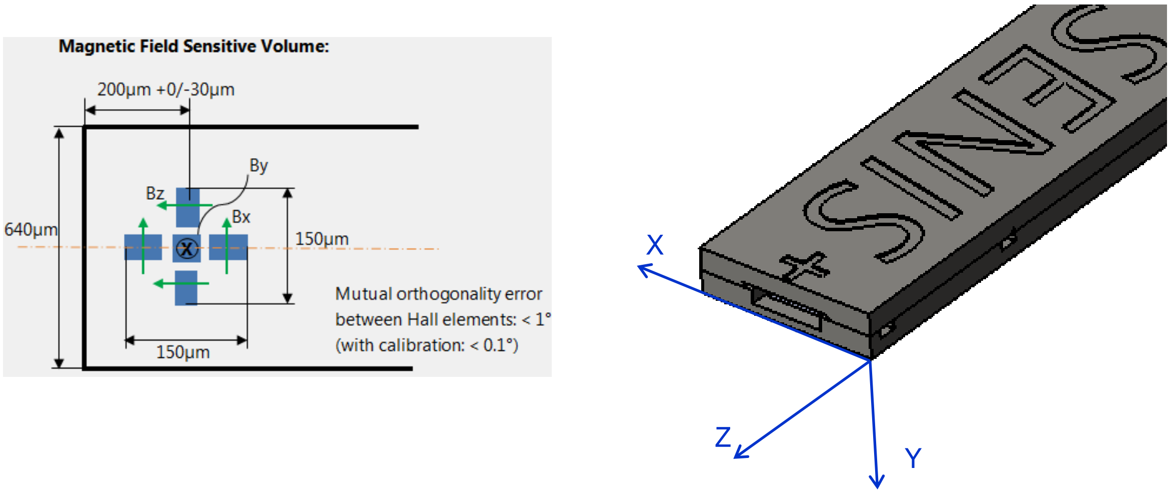


Figure 4. Left: Overall magnetic field sensitive volume (MFSV) of the applied fully integrated 3D Hall sensor.
Right: Reference Cartesian coordinate system of the HS Hall probe

<table>
<tr><th>Dimension</th><th>X [mm]</th><th>Y [mm]</th><th>Z [mm]</th></tr>
<tr><td>Magnetic field sensitive volume (MFSV)
(Figure 4)</td><td>0.15</td><td>0.01</td><td>0.15</td></tr>
<tr><td>Position of the centre of MFSV
(Figures 3 and 4)</td><td>1.00 ± 0.05</td><td>-0.50 +0.00/-0.05</td><td>-0.30 ± 0.05</td></tr>
<tr><td>External dimensions of the probe</td><td>2.00 ± 0.05</td><td>0.50 +0.05/-0.00</td><td>8.0 ± 0.2</td></tr>
<tr><td>Angular accuracy of the measurement axes</td><td colspan="3">< ±1° with respect to the reference surface
determined with accuracy better than ±0.1° during calibration</td></tr>
<tr><td>Hall Probe Cable (CaH)
- Construction and performances:</td><td colspan="3">Conductor: Silver plated soft copper core, 7 x 44 AWG
Insulation: PFA (Perfluoro Alkoxy), diameter 0.30 mm
Twisting: 15 x Diameter
Shield: Silver plated soft copper braid
Jacket: PFA (Perfluoro Alkoxy)
Service temperature: -196 / +200 °C
Linear resistance: 1.4 Ω/m
Rated voltage: 150 Vac
RoHS compliance: Yes</td></tr>
<tr><td></td><td colspan="3">Length:
▪ Standard: 2 m (Probe notation: F3A-03HS02C)
▪ Optional: X m (Probe notation: F3A-03HS0XC)
NOTE: Various cable lengths are available upon request.</td></tr>
</table>

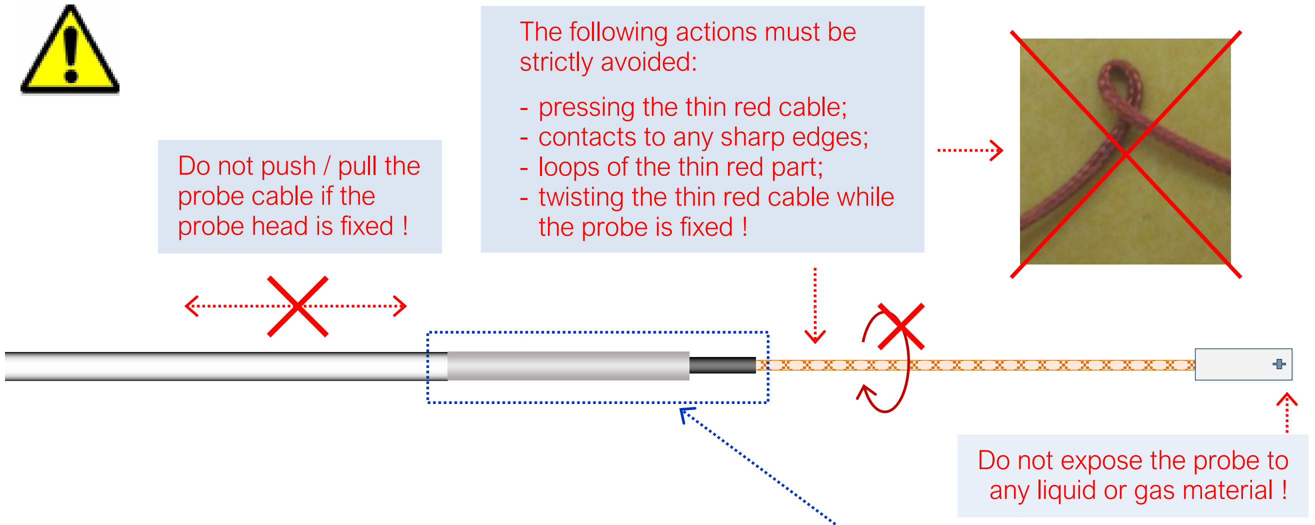
Installation Manual for the Hall probe type HS

WARNING: The Probe tip is fragile!
Please handle it with a special care.

The Hall probe type HS is a very small and mechanically sensitive sensor. Therefore, it should be handled with special care.

The following precautions should help to avoid damage to the probe during installation and handling, and ensure that accurate calibration of the device remains preserved:

- Always disconnect powering of the electronic module before plugging/unplugging the Hall probe!
- The Hall Probe is sensitive to Electrostatic Discharge (ESD). Please follow the proper ESD protection precautions when handling the Hall probe.
- Mounting of the Probe should be carried out by application of very low pressure to its head and particularly on the thin red cable.
- Do not apply more force than required to hold the probe in its place. Damage to either the ceramics package of the Hall sensor or thin red wiring could destroy the Probe.
- If the probe head is clamped, the user needs to make sure that the environment surface in contact with the reference plane of the probe is flat and covers as much of the probe reference surface as possible. Do not apply more force than required to hold the probe in its mounting.
- In order to prevent rupture of the thin probe wiring, the user should fix and secure the white probe cable prior to fixing the probe head. The thin red wire from the probe can be folded only with a special care. Strongly avoid loops of this section:



Do not push / pull the probe cable if the probe head is fixed !

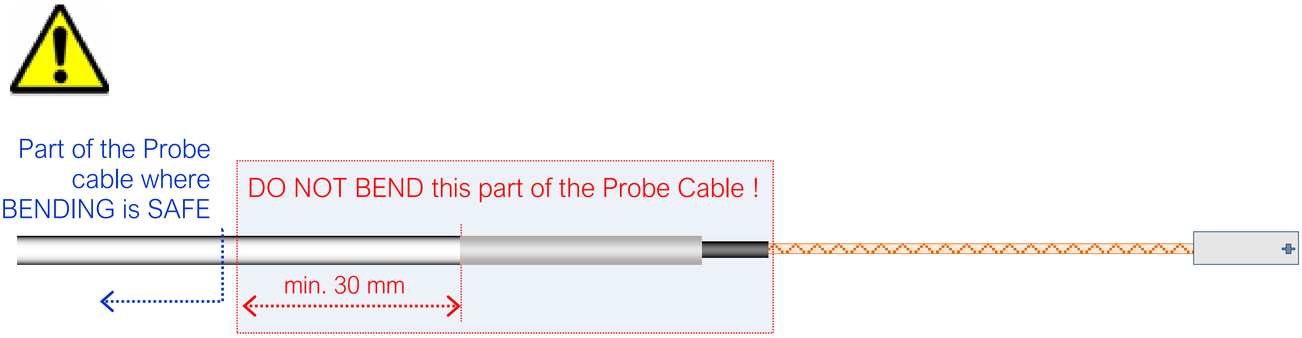
The following actions must be strictly avoided:

- pressing the thin red cable;
- contacts to any sharp edges;
- loops of the thin red part;
- twisting the thin red cable while the probe is fixed !

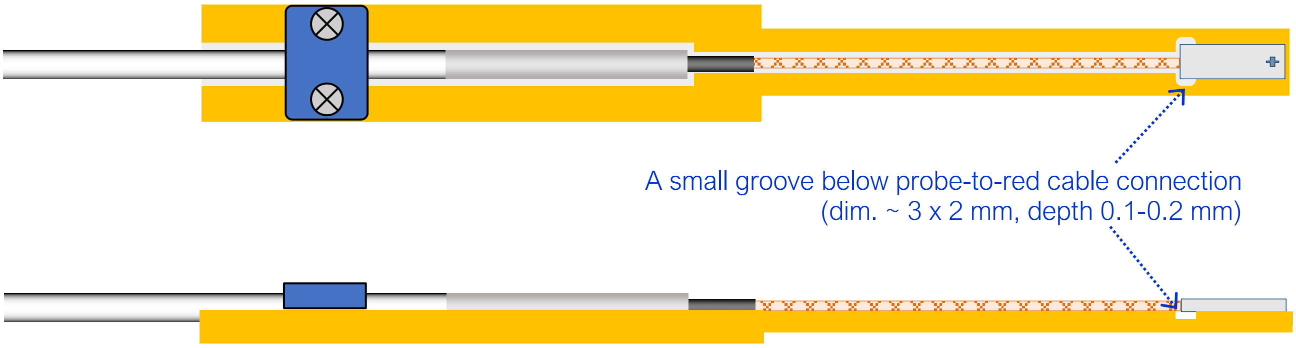
Do not expose the probe to any liquid or gas material !

- Do not expose the thin red cable to the external sharp edges.
- Do not expose the probe to moisture and aggressive gasses.
- Avoid the immersion of the probe in any liquid.
- Strongly avoid any high pressure, tightening and/or bending of the rigid (non-flexible) transient section between the thin (red) and thick (white) Probe cables.

- Safe bending area of the thick (white) probe cable is indicated in the following drawing:



- Proposal for a safe fixation of the HS Hall probe on a probe holder:



MAGNETIC and ELECTRICAL SPECIFICATIONS:

NOTE: Unless otherwise noted, please allow for 15 minutes warm up time to achieve optimal performances.
The listed specifications apply for all three measurement channels at room temperature (23 °C ± 1 °C).

PARAMETER		VALUE	REMARKS
Full scale magnetic flux density ($\pm B_{FS}$)		±2 T (±20 kG)	No saturation of the outputs
Linear range of magnetic flux density ($\pm B_{LR}$)		±2 T (±20 kG)	Fully calibrated meas. range
Measurement DC accuracy *@* $B \leq \pm B_{FS}$		< ±0.1 % of B_{FS}	See note 1
Output voltages (V_{out})		differential	See note 2
Sensitivity to DC magnetic field (S)		5 V/T (0.5 mV/G)	Differential output; See note 3
Tolerance of Sensitivity (S_{err}) *@* $B \leq \pm B_{FS}$		< 0.03 % of S	$100 \times \lvert S' - S \rvert / S$; Notes 3 and 4
Nonlinearity (NL) *@* $B \leq \pm B_{FS}$		< 0.05 %	See note 4
Planar Hall voltage (V_{planar}) *@* $B \leq \pm B_{FS}$		< 0.01 % of V_{normal}	See note 5
Temperature Coefficient of Sensitivity		< ±100 ppm/°C (±0.01 %/°C)	@ Temp. range 25 °C ± 10 °C
Long-term instability of Sensitivity		< 1 % over 10 years	
Offset *(@* $B = 0$ *T)*		< ±3 mV (±0.6 mT)	@ Temp. range 25 °C ± 5 °C
Temperature Coefficient of the Offset		< ±0.25 mV/°C (±0.05 mT/°C)	
Offset fluctuation & drift *(@ 0.01-10 Hz, i.e.* $\Delta t = 0.05$ *s,* $t = 100$ *s)*		< 0.5 mV_{p-p} (100 μT_{p-p})	Standard deviation (RMS) value: ≈ 85 μV_{RMS} (17 μT_{RMS}); See note 6
Output noise:			
Noise Spectral Density *@* $f = 1$ *Hz*	NSD_1	≈ 35 $\mu V/Hz^{1/2}$ (7 $\mu T/Hz^{1/2}$)	Region of **1/f** noise
Noise Spectral Density *@* $f > 10$ *Hz*	NSD_W	≈ 15 $\mu V/Hz^{1/2}$ (3 $\mu T/Hz^{1/2}$)	Region of **white** noise
Corner Frequency	f_C	≈ 10 Hz	Where 1/f-noise = white noise
Broad-band Noise *@* $f_C < f < Bw$	V_{nRMS-B}	< 0.9 mV_{RMS} (0.18 mT_{RMS})	RMS noise; See note 7
Resolution			See notes 6 - 10
Typical frequency response:			
Sensitivity attenuation < 0.1 %		< 50 Hz	Test: $B = 10mT \times \sin(2\pi ft)$ see page 8: AC Calibration Table-Frequency Response characterization
Sensitivity attenuation < 1 %		< 250 Hz	
Frequency Bandwidth (Bw)		≈ 2.5 kHz (-3 dB)	Sensitivity attenuation -3 dB; Note 11
Output resistance		< 10 Ω, short circuit proof	
Hall Probe Temperature output:			
Ground-referred voltage:		$V_{PT}[mV] = (T_{HALL}[°C] - 25\ °C \pm 3\ °C) \times 500\ [mV/°C]$ (T_{HALL} is the actual local temperature of the Hall sensor; See note 12)	
Magnetic Flux Density (B) units (T-tesla, G-gauss) conversion:			
1 T = 10 kG	1 mT = 10 G	1 μT = 10 mG	

MECHANICAL and ELECTRONICS SPECIFICATIONS (Module E):

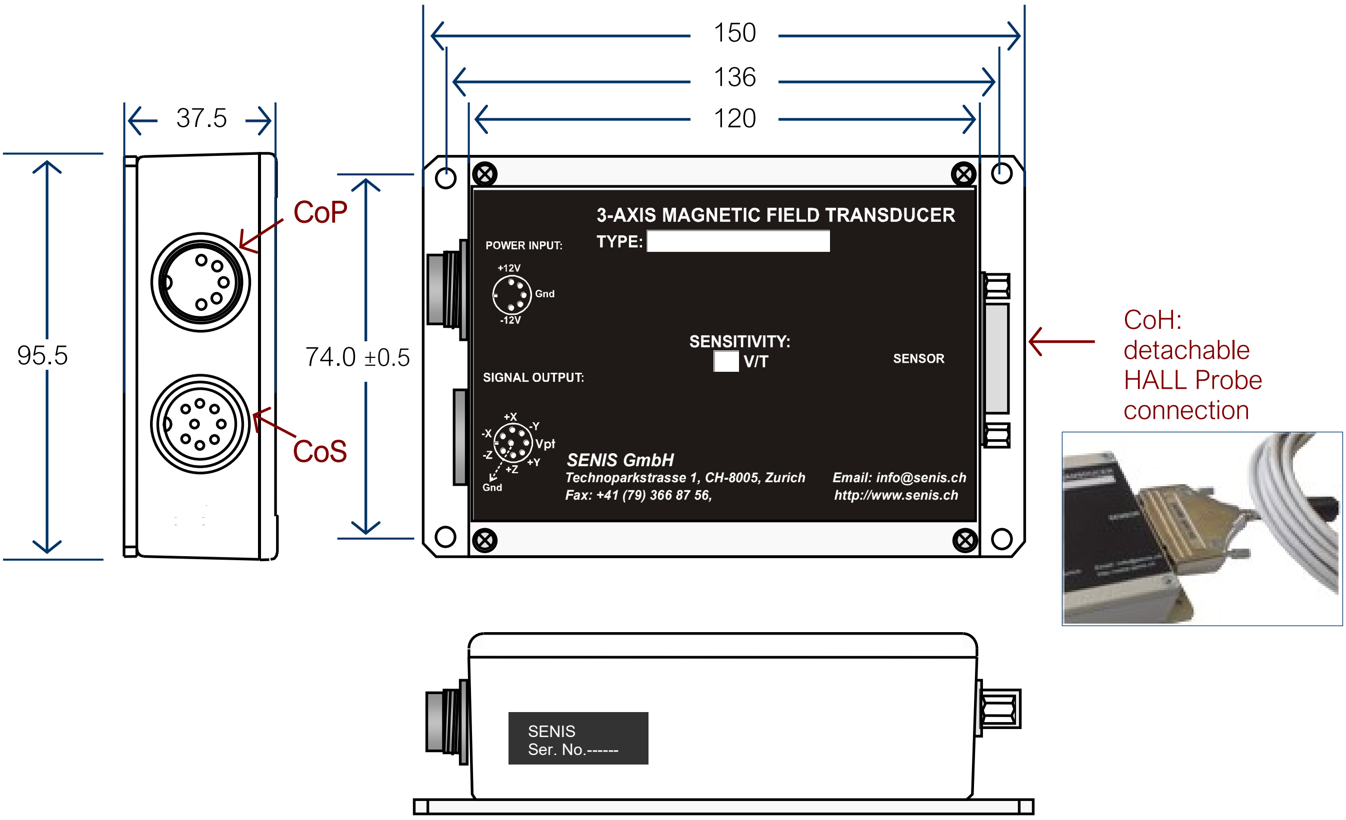


Figure 5. Dimensions and tolerances of the 3-channel analog E-Module type A02T2K5J

Module E		
Electronic chassis	High mechanical strength, electrically shielded aluminium case [95 **W** x 120 **L** x 37 **H** mm] with mounting provision (see Fig. 5)	
Connector CoS DIN KFV81, 8 poles (Mating plug SV81)	Field signal X+, X- Field signal Y+, Y- Field signal Z+, Z- Probe Temperature Signal common (GND)	Pins 1 and 6, respectively Pins 5 and 4, respectively Pins 3 and 7, respectively Pin 2 Pin 8
Connector CoP DIN SFV50, 5 poles (Mating plug KV50)	Power, +12 V Power, -12 V Power common (GND)	Pin 3 Pin 1 Pin 2
Connector CoH	Detachable connection:	Standard: D-SUB25, socket, 25-pins
DC Power	Voltage: Max. Ripple: Current:	±12 V nominal, ±2 % 100 mV$_{PP}$ ≈ 80 mA
Environmental Parameters:		
Operating Temperature	+5 °C to +45 °C	
Storage Temperature	-20 °C to +85 °C	

The ADDITIONAL CALIBRATION OPTIONS:

1. DC Calibration Table (V_{out} vs. B_{ref})

DC Calibration Table of the transducer can be ordered as an option. It is an Excel-file providing the actual values of the transducer output voltage for the test DC magnetic flux densities measured by a reference high-precision NMR Teslameter PT2025 or a high-accuracy 3-axis digital Teslameter 3MH6 (accuracy 100 ppm, verified against the NMR standard).

The standard DC Calibration Table covers the linear range of magnetic flux density $\pm B_{LR}$ in the steps of $B_{LR}/10$. Different DC calibration tables are available upon request.

By the utilisation of the DC Calibration Table, the accuracy of DC and low-frequency magnetic measurement can be improved almost up to the limit given by the resolution of the transducer (see Notes 1 and 6 - 10).

2. AC Calibration Table - Frequency Response characterization

Another option is the AC Calibration Table (Amplitude and Phase vs. Frequency) of the frequency response. This is an Excel file, providing the actual values of the transducer transfer function (complex sensitivity and Bode plots) for a reference AC magnetic flux density.

The standard AC Calibration Table covers the transducer frequency bandwidth from DC to *Bw*, measured in the steps of *Bw*/10. Different AC calibration tables are also available upon request.

By the application of the frequency response calibration table measurement accuracy of the AC magnetic field measurements can be improved almost up to the limit given by the AC resolution of the device (see Notes 1 and 6 - 11).

3-axis analog magnetic field transducer F3A-03HS02C-A02T2K5J is applicable in the B-frequency range from DC to 2.5 kHz (-3 dB point of sensitivity attenuation, where B being the density of the measured magnetic flux). In addition to the Hall voltage, at high B–frequencies also inductive signals are generated at the connection probe-thin cable. Moreover, the probe, the cable and the electronics in the E-module behave as a low-pass filter. As a result, the transducer has the "complex" sensitivity of the form:

$$S = S_H + jS_I$$

where:

- S_H represents sensitivity for the output signal in phase with the magnetic flux density (that is the real part of the transfer function);
- S_I is the sensitivity with the 90° phase shift with respect to the magnetic flux density (i.e., the imaginary part of the transfer function).

Calibration data can be ordered for S_H and S_I for all three measurement axes (Bx, By, and Bz) as an option. This allows the customer to deduce accurate values of the measured magnetic flux density at even high frequencies by an appropriate mathematical treatment of the transducer’s output voltages V_{out} .

NOTES:

1) Accuracy of the transducer is defined as the maximum difference between the actual measured magnetic flux density and that given by the transducer. In other words, the term accuracy expresses the maximum measurement error. After zeroing the offset at the nominal temperature, the worst-case relative measurement error of the transducer is given by the following expression:

Max. Relative Error: $M.R.E. = S_{err} + NL + 100 \times Res / B_{LR}$ [unit: % of B_{LR}] Eq. [1]

Here, S_{err} is the tolerance of the sensitivity (relative error in % of S), NL is the maximal relative nonlinearity error (see note 4), Res is the absolute resolution (Notes 6 - 10) and B_{LR} is the linear range of magnetic flux density.

2) The output of the measurement channel has two terminals and the output signal is the (differential) voltage between these two terminals. However, each output terminal can be used also as a single-ended output relative to common signal. In this case the sensitivity is approx. 1/2 of that of the differential output.

NOTE: Single-ended outputs are not calibrated.

3) Sensitivity (also: magnetic sensitivity) is given as the nominal slope of an ideal linear function $V_{out} = f(B)$, i.e.

$$V_{out} = S \times B \qquad \text{Eq. [2]}$$

where V_{out}, S and B represent transducer output voltage, sensitivity and the measured magnetic flux density, respectively.

4) Nonlinearity is the deviation of the function $B_{measured} = f(B_{actual})$ from the best linear fit of this function. Usually, the maximum of this deviation is expressed in terms of percentage of the full-scale input. Accordingly, the nonlinearity error is calculated as follows:

$$NL = 100 \times \left[\frac{V_{out} - V_{off}}{S'} - B \right]_{max} / B_{LR} \qquad (\text{for } -B_{LR} < B < -B_{LR}) \qquad \text{Eq. [3]}$$

Notation:

B	Actual testing DC magnetic flux density measured by a reference NMR Teslameter PT2025 or a high-accuracy digital Teslameter/gaussmeter 3MH6
$V_{out}(B) - V_{off}$	Corresponding measured transducer output voltage after zeroing the Offset
S'	Slope of the best linear fit of the function f(B) = Vout(B) – Voff (i.e. the actual magnetic sensitivity)
B_{LR}	Linear range of magnetic flux density

Tolerance of sensitivity can be calculated as follows:

$$S_{err} = 100 \text{ x } |S' - S| / S \qquad \text{Eq. [4]}$$

5) Planar Hall voltage is the voltage at the output of a Hall transducer produced by a magnetic flux density vector co-planar with the Hall plate. The planar Hall voltage is approximately proportional to the square of the measured magnetic flux density. Therefore, for example:

$$\left.\frac{V_{planar}}{V_{normal}}\right|_{@B=B_0} = 4 \text{ x } \left.\frac{V_{planar}}{V_{normal}}\right|_{@B=B_0/2} \qquad \text{Eq. [5]}$$

Here, V_{normal} denotes the normal Hall voltage, i.e., the transducer output voltage when the magnetic field is perpendicular to the Hall plate.

6) This is the *"6-sigma"* peak-to-peak span of offset fluctuations with sampling time Δt = 0.05 s and total measurement time t = 100 s. The measurement conditions correspond to the freq. bandwidth (0.01 - 10) Hz.

The *"6-sigma"* means that in average 0.27 % of the measurement time offset will exceed the given peak-to-peak span. The corresponding root mean square (RMS) noise equals 1/6 of "Offset fluctuation & drift".

7) Total output RMS noise voltage (of all frequencies) of the transducer. The corresponding peak-to-peak noise is about 6 times the RMS noise. See also Notes 8 and 9.

8) Maximal signal bandwidth of the transducer, determined by a built-in low-pass filter with a cut-off frequency *Bw*. In order to reduce the output noise or avoid aliasing, the frequency bandwidth may be limited by passing the transducer output signal trough an external filter (see Notes 9 and 10).

9) Resolution of the transducer is the smallest detectable change of the magnetic flux density that can be revealed by the output signal. The resolution is limited by the noise of the transducer and depends on the frequency band of interest.

DC resolution is given by the specification "Offset fluctuation & drift" (see also Note 6).

The worst-case (AC resolution) is given by the specification "Broad-band noise" (see also Note 7).

The resolution of a measurement can be increased by limiting the frequency bandwidth of the transducer. This can be done by passing the transducer output signal trough a hardware filter or by averaging the measured values.

Caution: Filtering produces a phase shift, and averaging causes a time delay!

The RMS noise voltage (i.e., resolution) of the transducer in a frequency band from f_L to f_H can be estimated as follows:

$$V_{nRMS\text{-}B} \approx \sqrt{NSD_{1f}^2 \times 1\text{Hz} \times \ln\left(\frac{f_H}{f_L}\right) + 1.16 \times NSD_W^2 \times f_H} \qquad \text{Eq. [6]}$$

Notation:

NSD_1	1/f noise voltage spectral density (RMS) @ f = 1 Hz
NSD_W	RMS white noise voltage spectral density
f_L and f_H	the low and is the high-frequency limit of the bandwidth of interest, respectively
1.16	numerical factor that comes under the assumption of using a third-order low-pass filter

For a DC measurement:

$$f_L = 1/\text{measurement time}.$$

The high-frequency limit cannot be higher than the cut-off frequency of the built-in filter *Bw*:

$$f_H \leq Bw.$$

If the low-frequency limit f_L is higher than the corner frequency f_C, then the first term in Eq. (6) can be neglected. Otherwise, if the high-frequency limit f_H is lower than the corner frequency f_C, than the second term in Eq. (6) can be neglected.

The corresponding peak-to-peak noise voltage can be calculated according to the *"6-sigma"* rule:

$$V_{nP\text{-}P\text{-}B} \approx 6 \times V_{nRMS\text{-}B}.$$

10) Let us denote this signal sampling frequency by f_{samS}. According to the sampling theorem, the sampling frequency must be at least two times higher than the highest frequency of the measured magnetic signal. However, in order to obtain the best signal-to-noise ratio, it is useful to allow for over-sampling (this way we avoid aliasing of high-frequency noise).

Accordingly, for best resolution, the recommended physical sampling frequency of the transducer output voltage is:

$$f_{samP} > 5 \times Bw,$$

or:

$$f_{samP} > 5 \times f_H$$ (if an additional low-pass filter is used; see Note 8).

The number of samples can be reduced by averaging each N subsequent samples, where $N \leq f_{samP} / f_{samS}$.

11) When measuring fast-changing magnetic fields, the one should take into account the transport delay of the Hall signals, small inductive signals generated at the connections Hall probe–thin cable and the filter effect of the electronics in the E-Module. Approximately, the transducer transfer function is similar to that of a third-order Butterworth low-pass filter with the cut-off frequency $f_{(-3\,dB)} = Bw$.

    The attenuation of the applied filter is -60 dB/dec (-18 dB/oct).
    The AC Calibration Table (Amp & Phase vs. Freq.) of the frequency response is available as an option.

12) The equation:

$$V_{PT}[\mathrm{mV}] = (T_{HALL}[^\circ\mathrm{C}] - 25\ ^\circ\mathrm{C} \pm 3\ ^\circ\mathrm{C}) \times 500\ [\mathrm{mV}/^\circ\mathrm{C}]$$

    is valid for the standard temperature range between +5 °C and +45 °C.

    The Probe temperature-proportional voltage output of the transducer (V_{PT}) is taken from a calibrated temperature sensor integrated in the CMOS Hall sensor. It therefore measures the actual local temperature of the Hall elements, but NOT the ambience temperature. Due to power loss in the sensor the sensor temperature is always higher than the environmental temperature.

    The difference between the temperature of the sensor (T_{HALL}) and the environment is more pronounced if the sensor tip is free hanging in the air. In this case the sensor is between 5 °C and 15 °C hotter than the environment (depending on the probe geometry and applied materials for the probe housing).

    If the sensor is well attached or clamped down on a heat conducting surface, such as a metal, the sensor is typically between 1 °C and 5 °C hotter than the environment.